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Effect of leaf and soil contaminations on heavy metals content in spring wheat crops

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Abstract Glasshouse experiments were carried out in Wagner pots containing 6 kg of soil. The amounts were compared of Zn, Pb and Cd taken up by the crop of spring wheat from contamination introduced into the soil or upon leaves. The heavy metals were labelled with the radioactive isotopes ^{65}Zn, ^{210}Pb and ^{115}Cd. The experiment was performed as a series of independent analyses in four replications. The dynamics of the labelled heavy metals translocation from contaminations sprayed on the upper or bottom side of the flag leaf was also tested. The highest concentration of ^{65}Zn was found in the straw and grain of wheat. Much higher amounts of the metals appeared to have been taken up by the plants from leaf contamination than from the soil. The highest dynamics of translocation from leaves to other vegetative and generative organs of plants was that of zinc.

Key words heavy metals • leaf contamination • soil contamination • spring wheat

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Introduction

Intensive development of industry, of transport and everyday technology has contributed to rise in heavy metals content in soils and crops to a level hazardous to populations inhabiting the affected regions. High concentrations of the metals exert, too, a negative influence on the development of plants, their use of nutrients and metabolism. In case of some heavy metals it is a rule that their raised amount in crops is accompanied with increased contents of other metals. For instance, in crops contaminated with cadmium there are usually observed excessive contents of zinc and lead [15]. Some amounts of heavy metals, particularly toxic cadmium, have been proved to be introduced into soil with mineral fertilizers, first of all with phosphatic ones [7].

Assimilation of Cd, Pb and Zn by plants from soil is highly dependent on the soil reaction. Many publications have confirmed the fact that Cd, Pb and Zn contents in soil solution evidently increased with drop in soil pH and rise in their total contents in the habitat [4, 5, 11]. Granulometric composition of soils and their sorption capacity appeared to be a decisive factor of heavy metals phytoavailability [2, 14]. High content of clayey particles in soil reduced the amount of contaminants in soil solution [1]. Quantitative participation of Cd and Zn bonded in sites of absorption with high affinity to them depend to a high degree on the time of reaching the state of equilibrium and saturation of clayey particle surfaces with ions [13].

The major objective of this study was to determine the relations in accumulation of zinc, lead and cadmium in grain and straw of spring wheat, the elements having been taken up through roots from the soil or through leaves. Besides, the dynamics of the metals translocation into the whole plant from contaminated upper and bottom leaf surfaces was also tested.

Materials and methods

Glasshouse experiments were carried out in 1993 using methods of independent analyses in four replications. The experiments were carried out in Wagner pots of 20 cm diameter, containing 6 kg of soil. The substrate used was a layer of brown humus soil, heavy loamy sand of pH in KCl = 4.7 containing 21% fine particles, 0.9% C org. as well as 16 mg K_2O and 12.6 mg P_2O_5 per 100 g soil (acc. to Egner). The test plant was spring wheat variety "Opolska". After thinning, the plant density was 12 in a pot, corresponding to 385 per sq. meter. Fertilization with macro – and microelements was applied according to the method commonly accepted for pot experiments [15]. In the stage of propagation and shooting the plants were fertilized with nitrogen at 1.5 g N per pot, introducing a NH_4NO_3 solution through a drain.

Soil moisture was maintained at a level of 60% maximum water holding capacity. The amounts were compared of labelled Zn, Pb and Cd accumulated in spring wheat, the contaminations having come from soils or from pollutants sprayed over leaves. The dynamics of the elements translocation into the plants from the upper and bottom sides of leaves was also tested. 0.1 M solutions of $ZnCl_2$, $CdCl_2$ and $Pb(NO_3)_2$ were labelled with the isotopes ^{65}Zn, ^{210}Pb and ^{115}Cd.

In tests carried out to determine the effectiveness of uptake from soil the following doses per pot were applied: 150 KBq ^{65}Zn, 1 MBq ^{210}Pb and 2.5 MBq ^{115}Cd 5 ml of 1 M solution of the proper element labelled with the isotope was introduced into 6 kg of soil and after a thorough mixing the contaminated substrate was put into the pots.

Considering continuous superficial contamination occurring in natural habitat, 1 ml of the labelled solution was introduced onto leaves in eight portions at equal time intervals. That dosage was applied from the propagation stage to the beginning of grain filling. The global doses were: 80 KBq ^{65}Zn, 1 MBq ^{210}Pb and 2 MBq ^{115}Cd. The contents of the radionuclides were determined in the final yield, i.e. in grain and straw. In experiments on the dynamics of the pollutants uptake through leaves, concentrations of the isotopes applied were hundred times higher than those applied to soil. 0.02 ml of the solution marked with a proper isotope was micropipetted onto the upper or bottom surface of the flag leaf. The preparation applied, diminishing the surface tension, allowed to obtain a series of small spots on the leaf surface. To determine the translocation dynamics of the pollutants, the plants were cut down (rejecting the contaminated leaf) after 1, 3, 7 and 23 days from the application of the labelled solutions. Accumulation of the pollutants in grain and straw was determined by measuring the radioactivity in respective weighed samples. The dynamics of the radionuclides translocation was analyzed in the whole plants, after rejecting the leaves which had been contaminated with the isotopes and incineration in a muffle furnace at 540°C. Measurements were performed by means of a scintillation probe with scintillators adequate to the kind of radiation and co-operating with the counting system. Depending on the couting rate the time of measurement was adjusted so that with least activity found in the grain the statistical measurement error did not exceed 12%. In the calculations, the radioactive disintegration was taken into account. In order to obtain normal distribution, rough results have been transformed according to the following formula:

$$y = \text{arc sin } (x)^{1/2}$$

Variance analysis and testing of the means were carried out on the grounds of transformed results; in Tables homogeneous groups are marked. The obtained results are presented in Tables 1–5.

Results and discussion

Analysis of the determined yields of the three isotopic labels is pointing out to significant differences in the uptake of the labelled elements. Wheat took up most zinc, somewhat less cadmium and significantly less lead as compared with the other elements (Table 1). When testing cereals in the shooting stage in the direct neighbourhood of copperworks E. Roszyk and S. Roszyk also found that the concentration of lead in wheat was lower than

Table 1. ^{65}Zn, ^{210}Pb, and ^{115}Cd taken up by spring wheat through leaves and from the soil (% of dose applied per pot in 1 g d.m. – mean values).

Part of plant	Source of contamination	Heavy metal markers		
		^{65}Zn	^{210}Pb	^{115}Cd
grain	soil	0.0328 a	0.0000 a	0.0092 a
	leaves	0.0459 b_1	0.0004 a_1	0.0101 a_1
straw	soil	0.0316 b_2	0.0005 a_2	0.0222 b_2
	leaves	0.4126 b_3	0.1367 a_3	0.3839 b_3

a, a_1–b_1, a_2–b_2, a_3–b_3 – weans with different letters are significantly differentiated

Table 2. Amounts of ^{65}Zn, ^{210}Pb and ^{115}Cd taken up by spring wheat through leaves and from the soil (% of dose applied per pot in 1 g d.m. – mean values).

Source of contamination		Part of plant	
Soil	Leaves	Grain	Straw
0.016	0.167	0.0164	0.1646

Table 3. Uptake of ^{210}Pb, ^{65}Zn, ^{115}Cd by spring wheat in 1 g d.m. (% activity of radionuclides introduced into the soil or upon the plant leaves).

Source of contamination	^{65}Zn	^{210}Pb	^{115}Cd
Soil	0.030 c	0.000 a	0.016 b
Leaf	0.229 b_1	0.069 a_1	0.197 b_1

a–c, a_1–b_1 – weans with different letters are significantly differentiated

Table 4. Uptake of ^{210}Pb, ^{65}Zn, ^{115}Cd by spring wheat in 1 g d.m. (% activity of radionuclides introduced into the soil and upon the plant leaves).

Part of plant	^{65}Zn	^{210}Pb	^{115}Cd
Grain	0.034 c	0.000 a	0.010 b
straw	0.286 c_1	0.091 a_1	0.203 b_1

a–c, a_1–c_1 – weans with different letters are significantly differentiated

that of other heavy metals [12]. Contamination through leaves appeared about ten times higher than that through roots from the soil (Table 2). Such a result was probably mainly due to the sorption properties of soil, in which the ions of the labelled elements introduced into the soil in solution were bound.
Importance of the sorption capacity of soil in case of heavy metals isotopes has been also reported by Haunold et al. [3].

In the grain of wheat the content of labelled metals was almost ten times lower than those found in the straw (Table 3). Kabata-Pendias has also pointed out serious limitation in the accumulation of heavy metals in cereal grain with their low (non-toxic) concentrations in the soil solution [6]. It may be supposed that low concentration of the three labelled elements found in our tests were also related with the dynamics of sorption processes and their low content in soil solution in the grain filling stage. Several authors emphasize significant differences in translocation of Zn, Pb and Cd, from soil to respective parts of plants [8, 10]. The accumulation capability may be arranged in the following order: root > stem > grain. The most effective uptake through leaves was that of labelled ^{65}Zn, while assimilation of lead was about four times lower. No measurable amounts of labelled lead were found in plants from the pots with contaminated soil (Tables 3, 4). The above finding has been in keeping with other authors' reports on most lead in crops coming from polluted air. They found higher concentrations of lead in plant leaves with larger surface and exposed to atmospheric pollution for a longer time

Table 5. Uptake of ^{65}Zn, ^{210}Pb, ^{115}Cd by wheat in 1 g d.m. (% activity of radionuclides deposited on leaves).

Isotope uptake by plant within		% of isotope uptake		
		^{115}Cd	^{65}Zn	^{210}Pb
1 day	t	0.167 a	3.49 a_1	0.162 a_2
	b	0.152 a	3.49 a_1	0.112 a_2
3 days	t	0.335 b	3.93 b_1	0.185 b_2
	b	0.327 b	7.39 b_1	0.202 b_2
7 days	t	0.485 c	14.12 c_1	2.022 c_2
	b	0.522 c	11.22 c_1	1.798 c_2
23 days	t	0.867 d	18.51 d_1	1.967 d_2
	b	0.998 d	15.93 d_1	2.008 d_2

t – top of leaf; b – bottom of leaf; a–d, a_1–d_1, a_2–d_2 – weans with different letters are significantly differentiated

[13]. The percentage of cadmium and zinc (0.020% and 0.016%), respectively (Table 3) in the plants analyzed, as in relation to the dose applied into soil, was contained within the limits of results obtained by other authors [10].

Although the boundary values of Cd and Zn uptake from brown soil highly exceeded the results obtained, nevertheless it was dependent also on the genotype of plants, particularly in creals being significantly differentiated [10]. From among the heavy metals tested the highest accumulation was that of zinc, lead being practically no threat to the crop (Table 4). Now, the concentration of lead in straw was about three times lower compared to those of zinc and cadmium (Table 4).

Low uptake and the low translocation of lead in the vegetative organs of wheat may result from lack of specific carriers (ion exchangers), which in case of zinc and cadmium may in a significant way influence the percentage of the elements cumulation in wheat grain.

In tests for the dynamics of Zn, Pb and Cd ions uptake through leaves, zinc was found to have been taken up in highest quantities and fastest translocated in the above-ground parts of wheat (Table 5). This fact has been also pointed out by Mascanzoni [9]. The dynamics of the tested heavy metals uptake from the surface of leaves appeared to maintain even up to 23 days after contamination. The process of cadmium and lead cumulation in the vegetative organs of wheat ran slower than that of zinc. No significant differences in assimilability of the elements tested were observed, depending on their deposition on the upper or bottom surface of lead blades.

Conclusions

1. From among the heavy metals tested spring wheat accumulated most zinc, somewhat less cadmium and considerably less lead.
2. Leaf contamination was a decisive factor of heavy metals contents in the above-ground parts of wheat, the amounts of zinc, cadmium and lead accumulated in grain were many times lower than those found in straw.
3. Zinc applied superficially translocated in the above-ground parts of wheat faster than cadmium or lead.
4. No significant differences were observed in the uptake of zinc, cadmium and lead from the upper or bottom surface of leaf blades.

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